Jovian Flyer – Engine Concept in First Approximation

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Abstract. From the beginning of the space era we have sent many probes and satellites to the other planets in the Solar System. However, most of them have no capability to fly in their atmospheres and to observe them from short distance. The only vehicles that successfully reached and conduct a flight in the atmosphere of planet other than the Earth were Vega-1 and Vega-2 atmostats (aerostat for planet that have no air) in 1985 on Venus. Some future missions are on development stage right now, but none of them is considering the usage of Flyer that uses classical airplane principals to perform a long flight in to the planets atmospheres. Our aim is to discuss the possibilities and the principals that will allow us to send that type of flying vehicle there. The best way to study the Solar system planets and mostly their atmospheres is to use Flyers (we will use the term "Flyer" instead of airplane, because there is no air on those planets). We pursuit few fundamental aims to deliver --- safely the Flyer, to provide a long flight that will make such mission to be meaningful, to develop an engine that can provide us with the trust needed for such a long flight --- possibly with a nuclear source of energy, to find an optimal observational equipment and a payload, to develop the proper test facilities etc.
There is a huge amount of unanswered questions in that field but there could be big benefits from that. The usage of Flyers that can do observations on the other planets will allow us to gather considerable amounts of information about the structure of the planets, about their atmospheres and climates, about their resources, about their history and etc.

Keywords: Flyer, Nuclear-Powered Ramjet Engine (NPRE), Jupiter Sea Level – JSL

1. INTRODUCTION

Over thirty probes have landed on the surface of the other planets in the Solar System. Almost none of them had the capability to fly. The only flying vehicles that conduct a flight in the atmosphere of other planet were Vega-1 and Vega-2 balloons in 1985 on Venus. They have flown over twenty thousand kilometers into it atmosphere and collected valuable scientific information (Sagdeev et.al, 1986a & Blamont et.al. 1986b). Some future missions are now in development phase, but most of them are planning the usage of atmostats or quadcopters but not a Flyer that uses classical airplane principals to perform a long atmospheric flight in planets different than the Earth. In this paper our aim is to discuss this possibility – the usage of Flyer on Jupiter, because this planet atmosphere is relatively well known.

The first problem to begin with is the exo-earth-engine that can give enough thrust to the Flyer. It must be simple enough. Because every additional part is increasing, the possibility of failure there must be as less as possible moving parts. The usage of electrical engine with solar panels will be able to fly on Venus, and there are such a projects (Landis G.A. 2001). The usage of electric engines with solar panels for Jupiter is not meaningful because in it atmosphere we can gather only 6% of the solar energy that we can gather on Earth, so it will give us too limited amount of thrust. This means that the Flyer will not be able to perform a stable flight taking into account the strong winds in the stratosphere. Because of the presence of H_2 and even some NH_3 Jupiter is suitable for internal combustion engines or even a jet engines with combustor chamber. It will need to carry an oxidizing agent for the combustion process, but the limitation of the oxidizer will lead to limitations on the flight time up-to one or two days. But this is meaningless, taking into account the price for such a mission – long flight is needed (Miller K. L., 1995 & Maise G. et.al 2003).

The only reasonable option is the usage of Nuclear-Powered Ramjet Engine (NPRE). It can give enough thrust for a long period of time and it is simple – can be designed with almost no moving parts. The aim of this work is to estimate the main characteristics of the NPRE.

2. THRUST CALCULATION

First to begin with is the flight environment. Jupiter has a thick atmosphere composed mainly from H_2 and He. For the service ceiling is decided to accept an altitude of 90 km (above the 1 Bar level – Jupiter Sea Level - JSL) because on that altitude the density is $\rho_{90\ \mathrm{km}} = 0.0018\ \mathrm{kg/m^3}$ that correspond to 50 km altitude on Earth. The gases above are too diluted. From other point of view the top cloud layer of the Jovian atmosphere lies on altitude of 50 km above the JSL and it determinates some border area. Above the clouds where there is an enough sunlight and below them. Nevertheless the flight could be concluded below the top cloud layer and these altitudes are actually an area of interest because of the little-known meteorology of the Jovian troposphere. It is possible to fly even below the JSL, but this is beyond the scope of this article. For the lower limit for the flight calculations, an altitude of 23.5 km is assumed, because below that altitude there is no full information of the physical conditions from the Galileo probe.

The main characteristics of the Jovian atmosphere are taken from the Galileo probe [1] and are used for the thrust calculations. The calculation methodic is taken from (Bondaryuk and Il'yashenko, 1958). The formula for the thrust is

$$P = G_4 v_4 - G_0 v_0 - \left(p_4 - p_0 \right) S_4 - X_a, \quad (1)$$

where G_4, G_0 p_0, p_4, v_0 and v_4 are the gas mass flow rate through the engine, pressure and velocity of the undisturbed flow and on the nozzle outlet section, P is the effective thrust, X_a is the additional resistance. If the design of the inlet allows the oblique shock waves to focus on the front edge of the diffuser then $X_a = 0$ or is negligible.

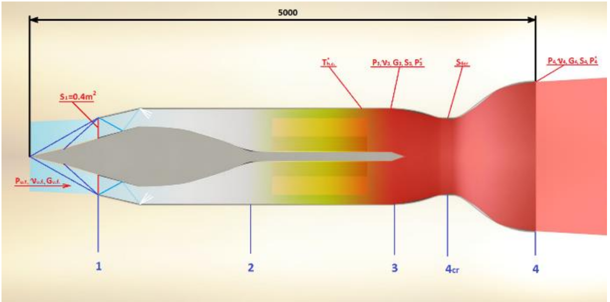

Figure 1. NPRE schematic and the engine sections.

The nozzle can be designed, so that the outflow pressure p_4 to drop to p_0 and the equation (1) is reduced to

$$P = G_0 \left(v_4 - v_0 \right), \quad (2)$$

where the velocity of the exit gases can be calculated from the equation

$$v_4 = \sqrt{2 \frac{\gamma R}{\gamma - 1} T_0^* \left[1 - \left(\frac{p_0}{\sigma_n p_{03}} \right)^{\frac{\gamma - 1}{\gamma}} \right]}. \quad (3)$$

We determine the heat capacity ratio as $\gamma = 1.4$ It is clear that it will change with the temperature $T^*_{\mathrm{h.c}}$ but the H_2 is the main component in the gas mixture and it is ranging between $\gamma = 1.35 \div 1.45$ for temperatures $T^*_{\mathrm{h.c}} = 200 \div 1500$ K. This value is similar to the data obtained by Galileo probe for these temperatures. The specific gas constant R is taken directly from the Galileo's measurements for the different altitudes. $T^*_{\mathrm{h.c}}$ can be chosen. σ_n can be determined for specific nozzle trough Computational Fluid Dynamics (CFD) simulations or by testing the nozzle in the same environment and in the same conditions, which requires the construction of special test facilities.

For the purpose of this article, in first approximation

$$\sigma_n = f\left(\frac{s_4}{s_3}\right) = \frac{p_{04}}{p_{03}} = 0.3 \qquad (4)$$

p_{03} can be calculated from the formula:

$$p_{03} = \sqrt{\frac{R}{\gamma}\left(\frac{\gamma+1}{2}\right)^{\frac{\gamma+1}{\gamma-1}}} \frac{\beta G_0 \sqrt{T_0^*}}{\sigma_n^{'} S_{4cr}} \qquad (5)$$

For our purposes here is enough to calculate the Lift-to-Drag ratio (L/D ratio) with Küchemann's relationship, namely for $M = 3$ it will be $k = 8$. Based on data of the hypersonic aircrafts and rockets that flied in Earth's atmosphere and the difference in the critical Reynold numbers, we assume that L/D ratio of $k = 5$ can be reached while designing the Jupiter's flyer. For the case of steady flight the lifting force than can be calculated from the thrust

$$k = \frac{L}{D} = \frac{F_{gravity}}{P} \qquad (6)$$

Here we would like to point out that this relationship was proved for the air and not for other gases. At the moment the any ideas how to reach L/D ratio do not exist. In particular this is because there are no designed flyers that are tested in wind-tunnel and there are no CFD simulations that were performed. This will be a matter of future work. to create ideas how exactly L/D ratio can be reached.

From the following relationship

$$L = F_{gravity} = kD = kP = 5P \qquad (7)$$

it is possible to calculate some main characteristics for a steady flight on different altitudes. If the lifting force is known, it is possible to make a conclusion for the mass of the flyer that can perform a steady flight at different altitudes. The results from the calculations are shown on the graphics for four different temperatures

$$T_{\text{h.c}}^{*} - 1500\ \text{K};\ 1200\ \text{K};\ 900\ \text{K};\ 600\ \text{K}.$$

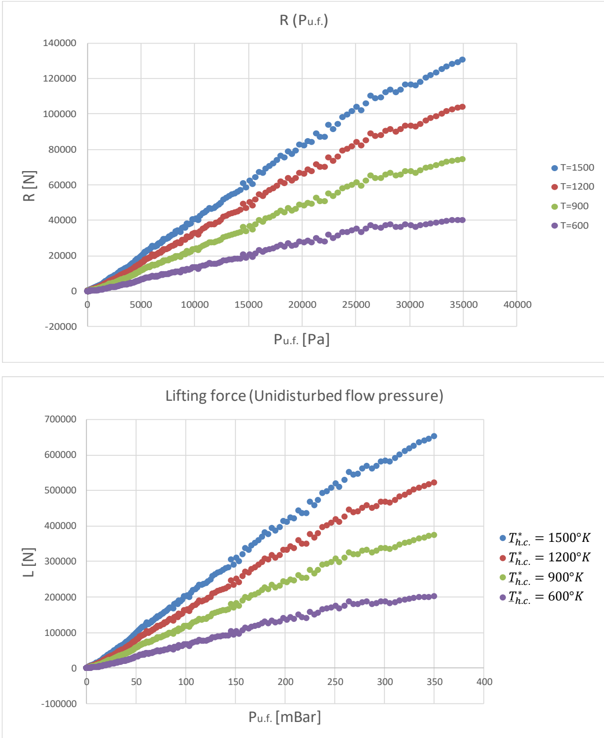

Fig. 2 Dependence of the thrust produced by the engine and the lift force to the atmospheric pressure at different altitudes above JSL calculated for four different temperatures of the stagnated flow in the engine heat chamber.

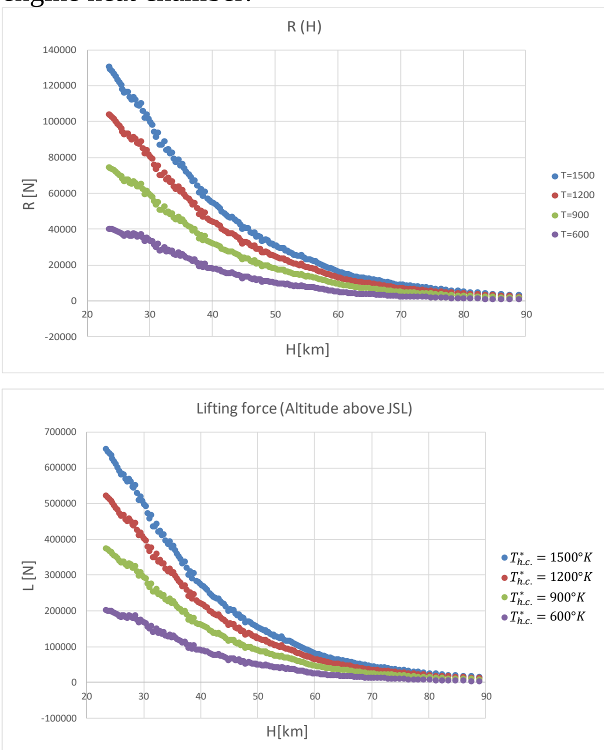

Fig. 3 Dependence of the thrust produced by the engine and the lift force at different altitudes calculated for four different temperatures of the stagnated flow in the engine heat chamber.

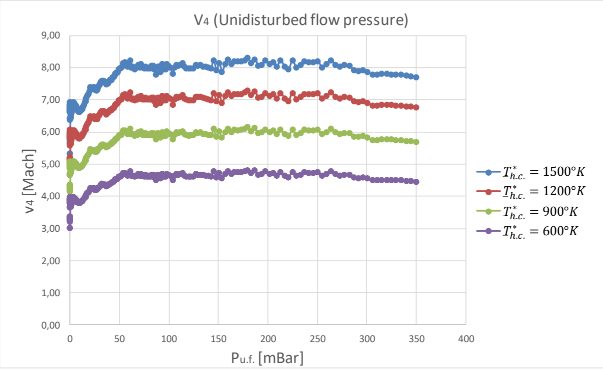

Fig. 4 Dependence of velocity of exhaust gases from the atmospheric pressure.

Interest is caused by a range of heights of 50-100 km. It is in this interval that the lifting force is sufficient to carry a Flyer with a mass of 1000 kg or 2000 kg.

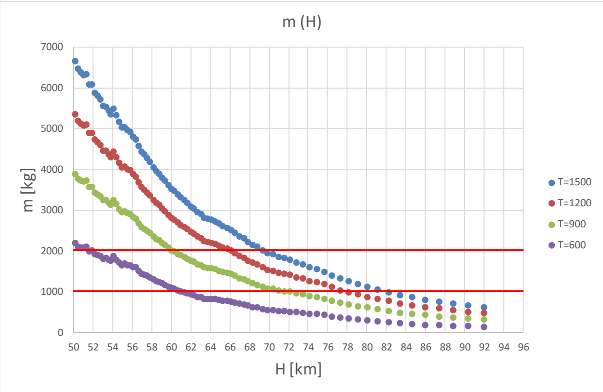

Fig. 5 As a result of the calculations of the thrust and the lift force at various temperatures inside the heating chamber, it is possible to conclude at what altitudes a steady flight of the flyer can be achieved. Two masses of the whole flyer are taken into account - 1000 kg and 2000 kg.

3. COMMENTS AND CONCLUSIONS

The main task of this paper was to make first steps to construct a flyer which eventually will be used for future exploration of some of the planets of the Solar System. Like an example in the paper was chosen the atmosphere of Jupiter.

It was found that for stable flying in the Jovian atmosphere the only reasonable option for the engine with which the flyer will be equipped is to be a nuclear-powered ramjet, called NPRE in the paper. The main advantages of such an engine are that it can give enough thrust for a long period of time and also it can be designed with almost no moving parts, which significantly simplifies the construction of the flyer.

In the paper, in first approximation, the main characteristics of the NPRE were estimated and it was found that the usage of NPRE that works with the gases from the Jovian atmosphere is possible due to the physical characteristics of the gases of the atmosphere of Jupiter.

As it was mentioned before the investigations are given in first approximation and many tasks which have to be solved are beyond the scope of our investigations and are left for future work. For example, the engine components such as the intake, the diffuser, the heating chamber, and the nozzle have to be designed. Also CFD simulations have to be done for the second approximation to compare the results with the calculations. The answers of these very important for the construction of the flyer questions will be given in future works.

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REFERENCES

Blamont J. E., Young R. E., Seiff A., Ragent B., Sagdeev R. Z., Linkin V. M., Kerzhanovich V. V., Ingersoll A. P., Crisp D., Elson L. S., Preston R. A., Golitsyn G. S. and Ivanov V. N., 1986b. *Implications of the VEGA balloon results for Venus atmospheric dynamics*, Science 231, 1422-1425.

Bondaryuk M. N. and Il’yashenko S. M., 1958. *Ramjet Engines*, Gosudarstvennoye Izdatelstvo Oboronnoy Promyshlennosti, Moscow, 515p.

Landis G. A., 2001. *Exploring Venus by Solar Airplane* presented at the STAIF Conference on Space Exploration Technology, Albuquerque NM, Feb. 11–15, 2001. AIP Conference Proceedings 552, 16–18.

Miller K. L., 1995. *Planetary Flight*, Journal of Propulsion and Power 11, 1063–1073.

Maise G., Powell J., Paniagua J., Kush E., Sforza P., Ludewig H. and Dowling T., 2003. *Application of the MITEE Nuclear Ramjet for Ultra Long Range Flyer Missions in the Atmospheres of Jupiter and Other Giant Planets* in Proceedings of the 54th International Astronautical Congress of the International Astronautical Federation, the International Academy of Astronautics, and the International Institute of Space Law; 29 September - 3 October 2003, Bremen, Germany.

Powell J. R., Paniagua J., Maise G., Hans Ludewig H. and Todosow M. 1999. *High Performance Nuclear Thermal Propulsion System for Near Term Exploration Missions to 100 A.U. and Beyond*, Acta Astronautica 44, 159-166.

Sagdeev R. Z., Linkin V. M., Kerzhanovich V. V., Lipatov A. N., Shurupov A. A., Blamont J. E., Crisp D., Ingersoll A. P., Elson L. S., Preston R. A., Hildebrand C. E., Ragent B., Seiff A., Young R. E., Petit G., Boloh L., Alexandrov Yu. N., Armand N. A., Bakitko R. V. and Selivanov A. S., 1986a. *Overview of VEGA Venus balloon in situ meteorologycal measurements*, Science 231, 1411-1414.

INTERNET RESOURCE

[1] NASA PDS: The Planetary Atmospheres Node, Galileo Probe Data Set Archive.